



## **Failures in Hybrid Microcircuits during Environmental Testing. History cases.**

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### **Purpose and Outline**

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#### **Purpose:**

To discuss failures in hermetic hybrids observed at the  
GSFC PA Lab. during environmental stress testing.

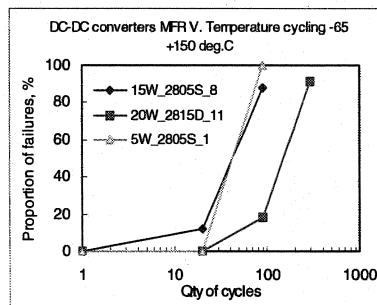
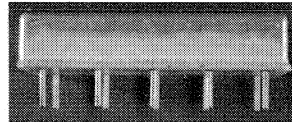
#### **Outline:**

- ☐ Case I. Substrate metallization failures during TC.
- ☐ Case II. Flex lid-induced failure.
- ☐ Case III. Hermeticity failures during TC.
- ☐ Case IV. Die metallization cracking during TC.
- ☐ How many test cycles and parts is necessary?
- ☐ Case V. WB failures after life test.
- ☐ Case VI. Failures caused by Au/In IMC growth.
- ☐ Conclusion.



## Case I. Substrate Metallization Failures during Temperature Cycling

- Hybrid DC-DC converters (5W to 20W) manufactured by different vendors were tested at -55, +25, and +125 °C after 20, 100, 300, and 1000 TC from -65 °C to +150 °C.
- Failures in parts manufactured by one vendor were observed starting 20 TC.
- Out of 20 tested parts 17 parts failed after 300 TC.
- Most parts failed at RT and 23% failed at -55 °C.



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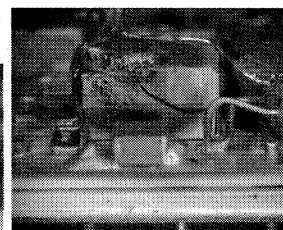
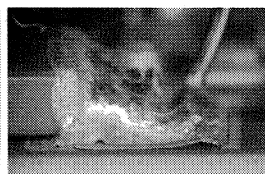
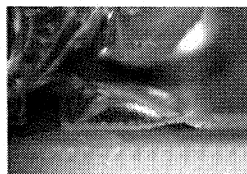
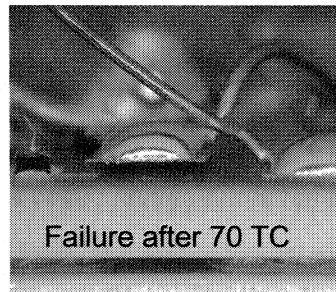


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## Case I. Results of Failure Analysis.

- Most failures were due to fractured metallization traces on the substrate near solder joints.
- Element and components are evaluated per MIL-PRF-38534.
- Failed Ta capacitor was observed in two cases.
- Capacitor failures might be caused by intermittent contacts.



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## Case I. Deficiencies of Substrate Qualification per MIL-PRF-38534.

- C.3.7... Substrates fabricated ...using a qualified process will be exempt from this evaluation.
- C.3.7.5.2.3... Perform film adhesion testing per acceptable industry standards.
- C.3.7.5.2.4... Perform solderability testing if specified in the applicable specification.  
(The test does not assess the effect of soldering on metallization).



TABLE C-V. Substrate evaluation requirements.

Subgroup	Class	Test	MIL-STD-883 Method	Quantity (accept number)	Reference paragraph
1	X X	Electrical testing		100 percent	C.3.7.3
2	X X	Visual inspection	2032	100 percent	C.3.7.4
3	X X	Physical dimensions	2016	5(d)	C.3.7.5.1.1
	X X	Visual inspection	2032		C.3.7.5.1.2
	X X	Electrical			C.3.7.5.1.3
4	X X	Conductor thickness or conductor resistivity		3(d)	C.3.7.5.2.1
	X X	Film adhesion test			C.3.7.5.2.2
	X X	Solderability			C.3.7.5.2.3
	X X	TCR		2(d)	C.3.7.5.3.1
5	X X	Wire bond evaluation	2011	10(d) wires or 20(1) wires	C.3.7.5.3.2
	X X	Die shear evaluation	2019	2(d)	C.3.7.5.3.3

Existing requirements do not address effects of soldering and TC on reliability of metallization.

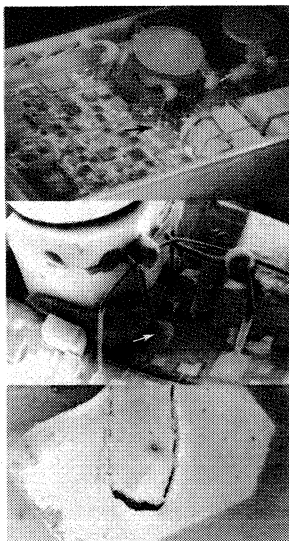
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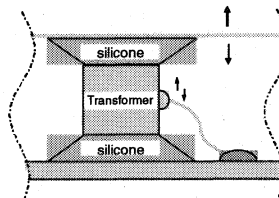
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## Case II. Flex-Lid-Induced Failures.



- A DC-DC converter failed during box-level testing in a thermo-vacuum chamber.
- The failure was due to a soldered joint fracture.
- Failed wire was secured to the transformer fixed to the lid with silicone.
- Mechanism of failure: low-cycling fatigue caused by deformation of the lid and shifts of the transformer and wire.



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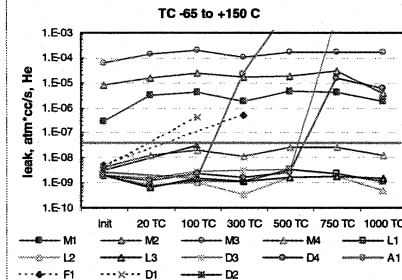


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## Case III. Hermeticity Failures during TC.

Variations of the Leak Rate with TC



- MIL-PRF-38534 requires 3(0) after 15 TS -65 to +150 °C for package seal evaluation.
- 5 out of 31 hybrids failed after 100 TC -65 to +150 °C.
- "Leaky" hybrids do not fail:  $\tau = P_0 V/L$ .

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$$\Delta P = P_0 \frac{\Delta T}{T_0}$$
 at  $\Delta T = 215^\circ\text{C}$   
 $\Delta P = 0.72 \text{ atm}$

$$\delta = \frac{pR^4}{64D}$$

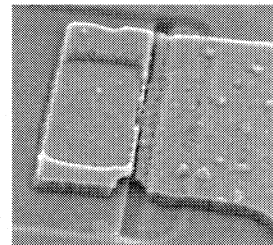
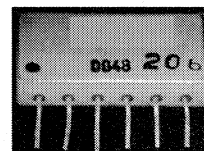
For a disc lid:

$D = E h^3 / [12(1 - \mu^2)]$  is lid rigidity.  
 At  $h = 0.38 \text{ mm}$  and  $R = 15 \text{ mm}$   
 $\delta = 60 \mu\text{m}$ .

Large-size hybrids might be more susceptible to hermeticity failures

## Case IV. Die Metallization Failure during TC.

- DPA has indicated a poor die metallization step coverage.
- Thinning of die metallization is typically considered as a reliability risk due to increased current density and possibility of electromigration failures.
- The parts passed life testing, but one out of 7 hybrids failed after 300 TC between -65 °C and +150 °C.



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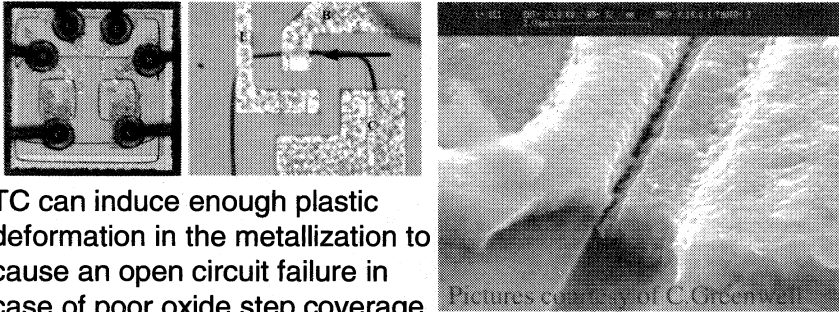


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## Case IV. Results of Failure Analysis.

- The failure was due to open circuit in the base metallization of a transistor.
- Mechanical stresses during TC resulted in low-cycling fatigue cracking of Al metallization and failure of the transistor.



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## How Many Test Cycles is Necessary?

- MIL-PRF-38534 requires 100 TC between -65 and 150°C,  $\Delta T_{ac} = 215^\circ\text{C}$ .
- Requirements for space projects differ substantially:
  - During a 2-year geostationary orbit (GEO) mission an instrument might experience ~700 TC between -20 to +40 °C,  $\Delta T_{op} = 60^\circ\text{C}$ .
  - During a 12-year low earth orbit (LEO) mission parts might be stressed by ~ 70,000 TC between -40 to +60 °C,  $\Delta T_{op} = 100^\circ\text{C}$ .
- Accelerating factor for TC:  $AF = (\Delta T_{ac}/\Delta T_{op})^m$   
Typically, for ductile materials  $m$  varies from 1 to 3, but for brittle materials it can be as high as 6 to 8.

m	AF		Required Nc	
	LEO	GEO	LEO	GEO
2	5	13	15143	55
4	21	165	3276	4
6	99	2117	709	1

100 TC -65 to +150 °C might be excessive for one project and not sufficient for another.

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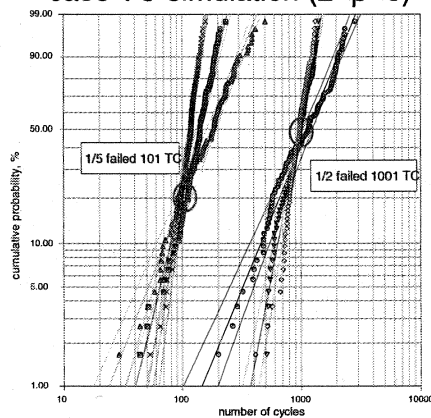
## How Many Test Samples is Necessary?

- MIL-PRF-38534 requires testing of 5 parts.
- Space-grade hybrids are expensive  $\Rightarrow$  only a few samples are available.
- Small sample size reduces the confidence in test results.

$$\lambda = \frac{\chi^2(c.l., 2n+2)}{2} \times \frac{1}{AF} \times \frac{1}{N \times M_c}$$

More confidence can be achieved by increasing the number of test cycles.

Weibull distributions of the worst case TC simulation ( $2 < \beta < 6$ )



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## Case V. Wire Bond Failures.

- Five hybrid solid state power controllers successfully passed life testing at 125 °C during 1000 hours.
- Additional electrical measurements after testing unexpectedly revealed open pins in two parts.
- The failures were caused by lifted 10-mil Al wires.
- Although Al wires are annealed, they are stiff and have built-in mechanical stresses, which might result in failures in bonds with weakened adhesion under minor mechanical disturbances.



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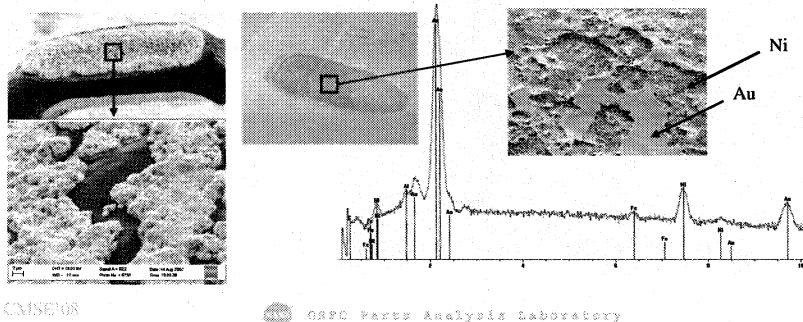


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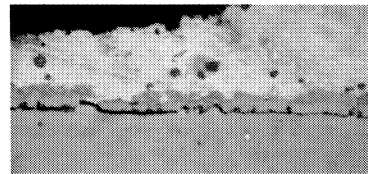
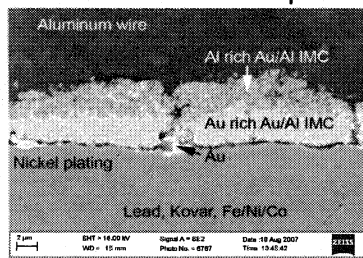
## Case V. Microstructure of Failed Bonds.

- Failed WBs were separated mostly along the nickel surface exposing relatively minor areas covered by gold.
- Most Au/Al IMC remained attached to Al wires and mating surfaces were ~80% covered with IMC thus indicating that the WBs were formed properly initially.
- No significant amount of contamination was observed during X-ray microanalysis of the failed bonds.



## Case V. Mechanism of Failure.

Cross section of Al wire-to-post bond



Purple and tan colors of the Au/Al IMC represent aluminum-rich,  $\text{AuAl}_2$ , and gold-rich,  $\text{Au}_4\text{Al}$  IMC.

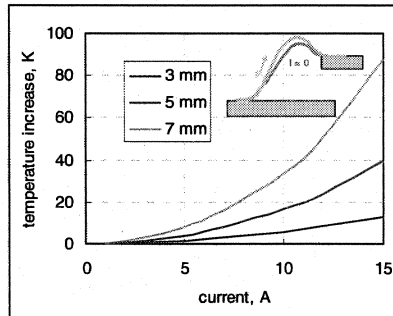
- Formation of Au/Al IMC at the Al/Au interface is a normal phenomenon.
- Au/Al IMC grow with time. At 125 °C all Au plating (~1 μm) is consumed in a few hours and a Ni/IMC contact is formed.
- In the presence of contaminations (Ti, Pb, As) Kirkendall microvoids accumulate resulting in failures (Horsting mechanism).
- Even a very low concentration of contamination (below the level of EDS sensitivity) might be sufficient to cause failures.

## Case V. Overheating of Wires.

- In power hybrids the risk of WB failures increases due to self-heating of wires.
- Overheating of wires causes deformation and stress in the bonds.
- Estimations show that for 5 mm long 10-mil Al wire at  $I = 15$  A the temperature might rise on 40 K, which would increase the wire length on  $\sim 4 \mu\text{m}$ .
- Power cycling might cause low-cycling fatigue in wire bonds.

$T_{\text{max}}$  in wires of different length

$$T_{\text{max}} = \frac{1}{\alpha} \left[ \frac{1 + \alpha T_0}{\cos\left(\frac{l}{2} \sqrt{C}\right)} - 1 \right] \quad C = \frac{I^2 \alpha \rho_0}{\lambda A^2}$$



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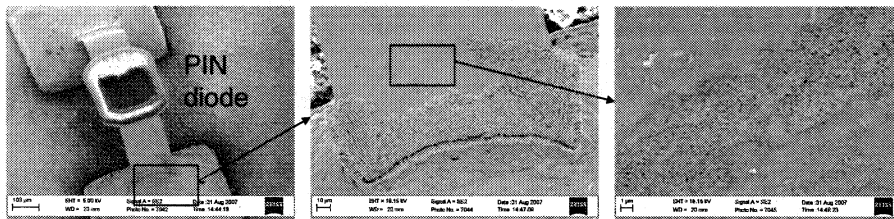


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## Case VI. Solder-induced Au/In IMC

- Microwave hybrids passed qualification testing including HTOL at 90 °C for 600 hrs.
- PIN diodes with gold beam leads (170  $\mu\text{m}$  X 5  $\mu\text{m}$ ) are installed using an indium-base solder, 80In/15Pb/5Ag.
- To evaluate the effect of In/Au IMC growth on mechanical strength of solder joints, the diodes were pull tested before and after HTS at 125 °C for 110 hrs.



Growth of IMC after 600 hrs at 90 °C occurs by diffusion of Au and In atoms across the thickness of the gold beam lead.

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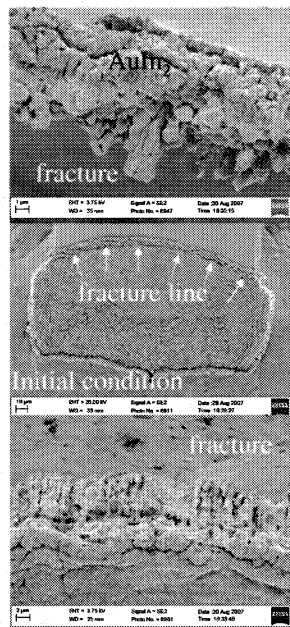
## Case VI. Pull Test.

- Fractures occur along IMC growth.
- 3 out of 7 diodes failed after HTOL and 5 out of 7 diodes after HTS.
- The central area of the Au leads was completely converted into a grainy and fragile  $\text{AuIn}_2$  composition.

Pull test results

Condition	Part #	D1	D2	D3	D4	D5
After HTOL 600 hr at 90 °C	16	-	11.8	-	11.7	-
	17	-	0.9	-	1.6	-
	18	0.24	14	5	-	-
After HTS 110 hr at 125 °C	16	0.26	-	3.2	-	-
	17	0.66	-	2.5	-	0.3
	18	-	-	-	8	8.3

Note: the calculated strength of the Au beams is ~13 g-f and the failure criteria is 4 g-f.



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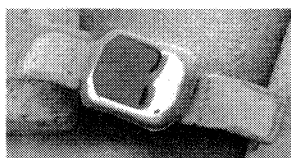


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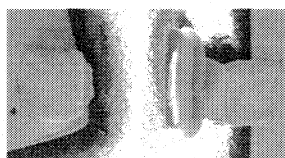
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## Case VI. Conversion of Entire Lead into Au/In IMC.

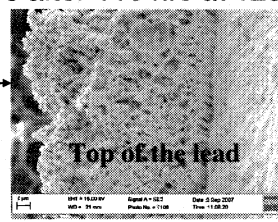
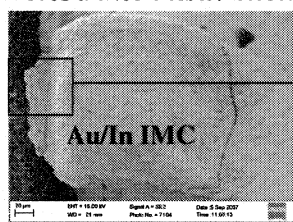
A diode in an initial condition and after HTS testing.



Pull test failure at 0.26g after HTS



Close-up views of the fractured lead. The gold lead is completely converted into Au/In intermetallics after 110 hrs at 125 °C.



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## Conclusion

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- ☐ TC might induce substrate metallization failures. MIL-PRF-38534, substrate evaluation, needs a revision.
- ☐ Lid flexibility might cause low-cycling fatigue failures in attached elements and lost of hermeticity.
- ☐ Poor metallization step coverage might cause failures due to low-cycling fatigue cracking.
- ☐ PoP approach is useful for estimation of TC test conditions.
- ☐ Al wire-to-Au-plated-post interconnections might fail due to accelerated IMC growth and microvoiding even at contamination levels below EDS sensitivity.
- ☐ To avoid failures in Au/Al interconnections, a highly accelerated aging test per MIL-STD-883, TM 2023 should be performed not only for substrate-to-substrate, but for substrate-to-package WBs as well.
- ☐ There is a significant reliability risk in using In-based solder to attach thin Au wires or ribbons. This attachment should be avoided in high-reliability systems.

